Fluid movement along the coronal two-thirds of root fillings placed by three different gutta-percha techniques

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Abstract

Wu M-K, van der Sluis LWM, Ardila CN, Wesselink PR. Fluid movement along the coronal two-thirds of root fillings placed by three different gutta-percha techniques. *International Endodontic Journal,* **36**, 533–540, 2003.

Aim To compare fluid movement (FM) along the coronal two-thirds of gutta percha/sealer root fillings placed by three different techniques.

Methodology Three groups consisting of the roots of mandibular incisors were instrumented and obturated by cold lateral compaction (LC), warm vertical compaction (VC) or the single-cone technique (SC), using RoekoSeal Automix (RSA) as the sealer. The apical 4 mm of each root filling was removed, and FM along the remaining 7 mm of the root filling was measured.

Results The VC group displayed more FM than the other two groups ($P = 0.023$). No significant difference in FM was found between the LC and SC groups ($P = 0.629$).

Conclusions The coronal two-thirds of the VC root fillings did not prevent FM when RSA sealer was used.

Keywords: leakage, sealer, setting time.

Received 12 June 2002; accepted 10 April 2003

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Introduction

During warm vertical compaction of gutta-percha, heat can be applied using heated hand instruments, a Touch 'n Heat (Analytic Technology, Redmond, WA, USA) device or the System B (Model 1005, EIE/Analytic). The temperature of the heat carrier of a Touch 'n Heat device may exceed 250 °C (Wu *et al.* 2002a), whilst that of the System B condenser often approaches 300 °C (Silver *et al.* 1999). During the heating procedure, not only the gutta-percha in the canal is heated but also the sealer. The use of heat has been found to increase the viscosity of some sealers (Himel & Cain 1993). Therefore, the original properties of the sealer may change at high temperature, and this could negatively influence the sealing ability of root fillings. Johnson & Bond (1999) reported noticeable amounts of dye penetration along the coronal two-thirds of root fillings. However, in their study, dye penetration along warm gutta-percha root fillings was not compared with dye penetration along cold gutta-percha root fillings. Thus, whether the dye penetration was caused by the use of heat or other factors is unknown.

According to the manufacturer, the RoekoSeal Automix (RSA) (Roeko, Langenau, Germany) sealer is biocompatible, insoluble, and creates a long-term seal and apical healing. In an 18-month longitudinal study of fluid penetration (Wu *et al.* 2002b), canals were filled by warm vertical compaction of gutta-percha with RSA as the sealer, the coronal two-thirds had been removed before the test was carried out, and the apical one-third of the fillings had minimal movement of fluid.

Single-cone gutta-percha (SC) root fillings would be expected to contain more sealer than cold lateral compaction (LC) or warm vertical compaction (VC) root fillings (Wu *et al.* 2000). Therefore, when a soluble sealer is used that may dissolve after some time, the SC fillings would be expected to allow more fluid movement than LC or VC root fillings (Kontakiotis *et al.* 1997). As RSA

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may be insoluble, the SC technique using the RSA sealer may be a promising filling technique.

Bacteria and their toxins are considered to be the main cause of apical inflammation (Kakehashi *et al.* 1965, Sundqvist 1976). Instrumentation and irrigation greatly reduce the number of bacteria but cannot completely remove them from the infected canals (Sjögren & Sundqvist 1987, Nair *et al.* 1990, Molander *et al.* 1998). Thus, root fillings are required to close the pathway of bacteria and toxin to the periapex (Molander *et al.* 1998).

Dye penetration has been frequently measured in order to compare the sealing ability of root-filling materials and techniques (Wu & Wesselink 1993). However, in an experiment conducted in animals, Pitt Ford (1983) failed to demonstrate a correlation between the length of linear dye penetration and the degree of inflammation. In 57% of the dye penetration measurements performed during a period of 10 years, dye penetrated less than 2 mm from the apical foramen (Wu & Wesselink 1993). Either the voids were of that length or the voids were longer, but dye penetration was hindered by the presence of entrapped air (Wu & Wesselink 1993, Dalat & Spangberg 1994). Very short, cul-de-sac-type voids located in the apical 2-mm of the root canal cannot provide pathways for bacteria and toxins that are present in the more coronal root canal. A wide void allows passage of more bacteria and diffusion of larger volumes of toxins to the periapex than a narrow void of the same length. Therefore, root fillings with wider voids may have a higher risk of failure than root fillings with narrow voids. However, voids of the same length, regardless of their diameters and volumes, lead to the same recording in linear dye penetration.

The fluid movement (FM) method was first used by Greenhill & Pashley (1981). According to Poiseuille's law (Pashley 1990, Van den Berg *et al.* 1993), fluid movement occurs in through-and-through voids only, whilst cul-de-sac-type voids prevent fluid movement. Therefore, detection of FM proves the existence of at least one through-and-through void along the root filling. This method provides volumetric data on fluid movement along root fillings. In the Poiseuille's formula (Pashley 1990, Van den Berg *et al.* 1993), the volume of fluid movement is determined by the length and diameter of the voids; FM varies with the fourth power of the void diameter but with the first power of the void length. Therefore, small changes in void diameter have a much larger effect on fluid movement than small changes in void length. Usually, the experimental groups in one study have roots of similar length so that the average length of the voids along the root fillings should not vary. Therefore, the effect of a difference in void length is likely to be negligible, and the detection of a high value for FM indicates the existence of wide through-and-through voids whilst a low-value FM indicates the existence of a narrow through-and-through void. Probably, this was why many investigators have considered FM along different fillings as a measurement of microleakage (Derkson *et al.* 1986, Pashley *et al.* 1988, Bates *et al.* 1996, Bachicha *et al.* 1998, Miletiæ *et al.* 1999, Abramovitz *et al.* 2001, Belli *et al.* 2001, Fogel & Peikoff 2001, Greer *et al.* 2001, Kontakiotis *et al.* 2001, Pommel & Camps 2001a,b, Pommel *et al.* 2001, Timpawat *et al.* 2001, Cobankara *et al.* 2002).

Comparing dye penetration and FM, it can be considered that: (i) FM suggests pathways between the coronal and the apical end of a root filling, i.e. through-and-through voids, rather than apical cul-de-sac-type voids; (ii) FM values indicate the diameter and length of the void, rather than the length of the void only. However, whether there is a correlation between the FM along root fillings and the degree of periapical inflammation has not been studied.

In this study, root canals were filled with RSA sealer using three different techniques (LC, VC and SC). The purpose was to measure FM along the coronal two-thirds of the root fillings remaining in mandibular incisors after removing the apical filling. In order to obtain more information on the quality of the filling, the cross-sections of the coronal two-thirds of the root fillings were also evaluated by measuring the percentage area filled with gutta-percha and sealer.

Materials and methods

Sixty mandibular incisors with a single oval canal were selected after mesio-distal radiographs indicated a bucco-lingual internal diameter of >0.6 mm at a level 5 mm from the apex. These 60 teeth were divided into three equal groups ($n = 20$) on the basis of their bucco-lingual internal diameters. The techniques used in the three groups were LC, VC and SC.

Instrumentation

The coronal part of each tooth was removed by means of an Isomet 11-1180 low-speed saw (Buehler Ltd, Evanston, IL, USA), leaving roots 12 mm in length (Fig. 1). The working length was set at 11 mm.

The coronal portion of each canal was preflared using a size 2 Gates–Glidden drill (Dentsply Maillefer, Ballaigues, Switzerland) inserted 6 mm from the apex.

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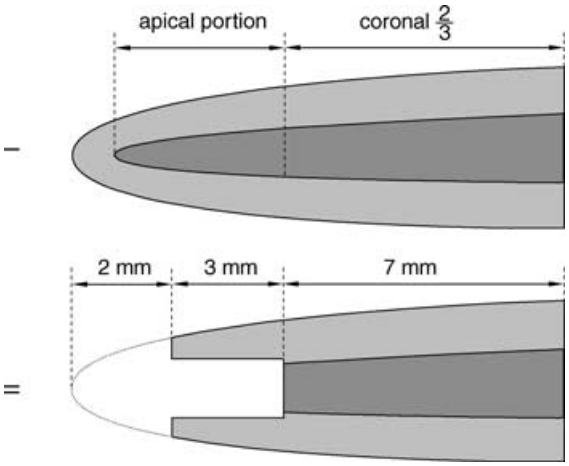

Figure 1 Schematic representation of specimen preparation. I,The coronal two-thirds was filled by the backfill, whilst the apical one-third was filled by the down-pack; II, the remaining 7 mm of root filling after removal of the apex and the apical 3 mm of root filling.

All canals were prepared with Flexofiles (Dentsply Maillefer), using a circumferential filing technique. Sizes 15–40 were subsequently inserted to the working length, and a size 40 file was accepted as the master apical file. File sizes 45, 50 and 55 were used to depths of 1, 2 and 3 mm short of the working length, respectively.

Each canal was irrigated with 2 mL of a freshly prepared 5% solution of sodium hypochlorite, using a syringe and a 27-gauge needle between each file. After completion of hand instrumentation, each canal was irrigated with a 2% NaOCl solution and an Endosonore file size 15 (Dentsply Maillefer), oscillating in a bucco-lingual direction for 3 min using the Piezon Master 400 (EMS, Le Sentier, Switzerland).

Filling

RoekoSeal Automix (RSA) root-canal sealer (Roeko, Langenau, Germany) was placed into each root canal with a nickel–titanium EZ-Fill bidirectional spiral (Cat. no. 1605-00, EDS, Hackensack, NJ, USA) that was slowly rotated at approximately 1000 r.p.m.

In the LC group, a size 40 master cone (Dentsply Maillefer) lightly coated with sealer was placed in the canal to the full working length. Lateral compaction was achieved in each canal by using size 25 accessory gutta-percha cones, together with an endodontic finger spreader size B (Dentsply Maillefer), which initially reached to within 2 mm of the full working length. More than eight accessory gutta-percha cones were used in each canal, and the tip of each was lightly coated with sealer. A heated instrument was used to remove the excess gutta-percha, and then vertical force was applied with a plugger (0.8 mm diameter, Dentsply Maillefer) to compact the gutta-percha in the coronal portion of the canal.

In the SC group, a size 40 gutta-percha cone lightly coated with sealer was placed in the canal to the full working length. A heated instrument was used to remove the excess gutta-percha.

In the VC group, a size 40 gutta-percha cone lightly coated with sealer was placed into the canal to the full working length. In order to increase the amount of gutta-percha, two additional size 25 gutta-percha cones were placed as far as possible into the canal. The heat source was standardized by the use of Touch 'n Heat (Model 5004, Analytic Technology, Redmond, WA, USA) at a power setting of 10. Each time, the gutta-percha was heated for 4 s. The gutta-percha was heated by inserting the heat carrier thrice into each canal (coronal, middle and apical). Vertical force was applied using a plugger 50 B (Dentsply Maillefer) to compact the gutta-percha in the coronal portion of the canal. Pluggers 40 B and 30 B (Dentsply Maillefer) were used to compact the gutta-percha in the middle and apical portions of the canal, respectively. A sustained push was carried out for a few seconds with the last plugger. Filling of the rest of the canal space was achieved by injecting warm gutta-percha using the Obtura II (Obtura Corporation, Fenton, MO, USA), each time injecting a 3–4-mm segment and compacting the gutta-percha with a pre-fitted plugger.

FM test

The filled roots were then stored at 100% humidity and 37 °C for 2 weeks. The apical 4 mm of the root fillings was then removed as follows (Fig. 1). A 2-mm section of the apical end of the root was removed with a high-speed diamond fissure bur (ISO size 010) with water cooling. Apical root-end cavities, 3 mm in depth, were then prepared using an ISO size 006 inverted-cone carbide bur (Komet, Brasseler GmbH, Lemgo, Germany) operating at low speed (approximately 8000 r.p.m.), leaving the coronal 7 mm of root filling intact.

Each root was embedded in an acrylic resin cylinder. The coronal and apical ends of the remaining root fragment were not included in the resin cylinder. The margins adjoining the acrylic resin and the root were sealed with cyanoacrylate (Permacol, dispenser PX-10, Ede, the Netherlands). The roots were mounted in the

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FM device previously described by Wu *et al.* (1993). The smooth surface of the resin cylinders ensured a good fit with the plastic tubes of the FM model. A plastic tube filled with water was connected to the inlet end of the resin cylinder, i.e. the coronal end of the root fragment. A headspace pressure of 60 kPa (0.6 atm) was applied in the plastic tube. A standard glass capillary in which an air bubble was introduced was connected to the outlet end of cylinder, i.e. the apical end of the root fragment. Movement of water was recorded by displacement of the air bubble. All connections were closed tightly by twisting pieces of stainless steel wire around the plastic tubes whilst immersed in a water bath at 20 °C. It was essential to do this under water, in order to prevent back movement of the air bubble (Wu *et al.* 2001a). After connecting the specimen to the set-up and introducing an air bubble in the capillary, the system was left overnight before starting the pressure and measurement, allowing the relaxation of the elastic tubing that had been pressed by the wire. The volume of fluid movement was recorded after 1, 3 and 5 h. The results after calculation were expressed as $\mu L\ min^{-1}$.

Cross-section of root filling

Using a low-speed saw (Sägemikrotom 1600, Leitz, Wetzlar, Germany) with water coolant, each root was horizontally sectioned 6 mm from the coronal end of the root fragment, i.e. 6 mm from the apex (Fig. 1; Wu *et al.* 2001a). By means of a digital camera, pictures of the sections were taken using a Photomakroskop M400 microscope (Wild, Heerbrugg, Switzerland) at $\times 40$ magnification; the pictures were scanned as Tagged Image File Format (TIFF) images. Using a KS100 Imaging system 3.0 (Carl Zeiss Vision GmbH, Hallbergmoos, Germany), the canal area, the gutta-percha-filled areas and the sealer-filled areas were measured. The percentage of the gutta-percha- and sealer-filled areas was calculated.

Positive and negative controls

In this study, six mandibular incisors were used as negative controls. The entire tooth was coated with nail varnish. The purpose of the negative controls was to demonstrate that the model system prevented movement of fluid. Another six mandibular incisors served as positive controls; the root canal of each tooth was prepared and filled with a few gutta-percha cones, without the use of a sealer. The purpose of the positive controls was to demonstrate the sensitivity of the system whenever the canal was not completely filled. Each control root was also embedded in an acrylic resin cylinder as for the experimental roots. FM along both negative and positive controls was measured using the same method as for the three experimental groups.

Statistics

The difference between the groups with respect to the percentage of the specimens that did not prevent FM was analysed by means of chi-square test. The difference between the groups with respect to leakage and the percentage of canal area filled with gutta-percha and sealer was analysed by means of Kruskal–Wallis and Mann–Whitney *U*-tests. The level of significance was set at $p = 0.05$.

Results

Up to 5 h after the test, no movement of the air bubble was detected in the negative controls, whilst in all positive controls, the air bubble moved so rapidly that it could not be measured, which means that the bubble moved faster than 10 $\mu L\ min^{-1}$.

The mean FM results are shown in Table 1. Three teeth in the SC group were excluded because the entire root filling was displaced coronally during preparation of the retrograde cavities. Thus, FM was measured along 57 filled roots (Table 1). In all, 10 roots (18%) displayed FM: two in the LC group (10%), one in the SC group (6%) and seven in the VC group (35%). The percentage of the specimens that did not prevent FM was significantly higher in the VC group than in the other two groups ($P < 0.05$). For the other 47 roots, the air bubble did not move during a period of 5 h. As Table 1 shows, the fluid movement for each group remained constant during the 5 h ($P = 0.992$ for the LC; $P = 0.794$ for the VC;

Table 1 Mean leakage of 57 teeth filled by different techniques in $\mu L\ min^{-1}$, as affected by measurement time

	Measurement time		
Filling technique	1 h	3 h	5 h
Lateral compaction ($n = 20$)	0.015 ± 0.067	0.013 ± 0.058	0.013 ± 0.058
Single cone ($n = 17$)	0.001 ± 0.002	0.001 ± 0.002	0.001 ± 0.003
Vertical compaction ($n = 20$)	0.315 ± 0.550	0.300 ± 0.561	0.294 ± 0.561

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Table 2 Percentage of gutta-percha (GP)- and sealer-filled areas

Filling technique	Mean and SD of GP-filled area in %	Mean and SD of sealer-filled area in %	Mean and SD of GP and sealer-filled area in %
LC ($n = 20$)	90.1 ±6.5	9.2 ± 6.2	99.3 ± 1.0
SC ($n = 17$)	39.0 ± 16.0	60.7 ± 15.9	99.7 ± 1.0
VC ($n = 20$)	96.2 ± 6.3	3.7 ± 0.7	99.9 ± 0.6

LC: Lateral compaction; SC: single cone; VC: vertical compaction.

$P = 0.742$ for the SC). The VC group displayed more FM than the other two groups ($P = 0.023$ at 1 and 3 h; $P = 0.048$ at 5 h). This significant difference made possible further comparisons between each set of two groups through the use of the Mann–Whitney *U*-test. As the extent of FT for each technique remained constant during the 5 h, comparisons between each two techniques were performed on the basis of the 1-h data only. A significant difference was found between the LC and VC ($P = 0.042$) groups and between the SC and VC ($P = 0.025$) groups, but not between the LC and SC groups ($P = 0.629$).

Although the percentage of gutta-percha-filled area recorded for VC was the highest and that for SC was the lowest (Fig. 2; Table 2), the percentage of the gutta-percha- and sealer-filled canal areas was close to 100% in all three groups ($P = 0.393$; Table 2). In the cross-sections of 50% of the roots in the VC group, sealer was found to be present not in a thin layer, but rather in large areas which were of a granular appearance (Fig. 3). During the obturation, it was found that hard sealer fragments were being pressed out of the root-canal orifices. In the LC group, a large canal area was filled with a number of gutta-percha points, and the remaining area was filled with sealer (Fig. 4).

Discussion

During setting, the polymerization stress within a sealer cement may lead to formation of voids either within the sealer substance (by cohesive failure), between sealer and dentine or between sealer and gutta-percha (by adhesive failure). According to Poiseuille's law (Pashley 1990, Van den Berg *et al.* 1993), the movement of fluid along root fillings should occur as a proof of these voids. Bacteria and their toxin and tissue fluid may penetrate along the filled roots through these voids. One may argue that water infiltration through the substance of a root or along filling materials may also displace the air bubble even when no void exists, and that such water movement should not be considered as leakage. This assumption should be rejected because many specimens in previous studies where gutta-percha and various sealers had been used (Wu *et al.* 1993; 2001a, 2001b; 2002b), and 47 test specimens in the current study where gutta-percha and RSA sealer had been used, showed stable positions of the air bubbles for the whole measurement period (in this study, 5 h).

Six teeth completely coated with nail varnish served as negative controls and showed stable positions of the air bubbles during 5 h, and thus no fluid movement. Thus,

Figure 2 Cross-section of a single-cone filling. The canal area that was not filled with gutta-percha point was completely filled with the RSA sealer. No dentine debris was visible. No leakage was detected in this sample.

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Figure 3 Cross-section of a warm vertical compaction root filling. This was a long oval canal. A large mass of set sealer with a granular appearance was found at one side of the canal. This sample leaked 1.125 μL min^{-1}.

any displacement of the air bubble during the study was not caused by a system error but rather through at least one through-and-through void.

Re-infection of the canal and seepage of tissue fluids from the apical end of the canal that may provide the residual bacteria with a nutritive substrate should be prevented. The rationale of filling a root canal, therefore, is to fill the entire canal and have no potential for bacterial penetration from the coronal end of the root and no potential for penetration of tissue fluid from the apical end of the canal. When FM occurred along a root filling, there was a communication between the two ends of a root filling.

This study focused on oval canals, which are difficult to clean and obturate (Lumley *et al.* 1993, Wu & Wesselink 2001, Wu *et al.* 2001a). Instrumentation produces a large amount of dentine debris in the root canal, which is not always completely removed. The dentine debris left behind may block the root canal (Al-Omari & Dummer 1995). It has been shown in studies by Wu & Wesselink (2001) and Wu *et al.* (2001a) that, without efficient irrigation, part of the canal can remain occupied by dentine debris. In this current study, ultrasound irrigation was performed and the portion of canal area filled with gutta-percha and sealer approached 100% in all three groups (Table 2), indicating that the canals were free of microscopically visible debris prior to obturation. However, only one cross-section was used at 6 mm from the apex, and whether, at all levels, the canals were free of debris is unknown.

Figure 4 Cross-section of a lateral compaction root filling. This was a long oval canal, and the canal area that was not filled with gutta-percha points was completely filled with sealer, indicating the ability of bidirectional spiral to deliver sealer into lateral invaginations. No dentine debris was visible. No leakage was detected with this sample.

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In a study by Wu *et al.* (2002b), which measured FM along the apical one-third of root fillings, both the VC and LC techniques with RSA sealer had minimal movement of fluid. In the present study, which evaluated FM along the coronal two-thirds, VC displayed significantly more FM. Fluid movement was detected in 35% of the specimens in the VC group, compared to 10% in the LC group and 6% in the SC group ($P < 0.05$), indicating the existence of through-and-through voids. The FM values for the VC group indicated that the diameters of voids were higher than those for the other two groups (Table 1; $P < 0.05$). During obturation, fragments of set sealer were forced out of the root-canal orifice. In cross-sections, the RSA sealer had a granular appearance (Fig. 3), which was not seen in the LC- or SC-filled canals (Figs 2 and 4). It may be that the RSA sealer had already set before filling the coronal two-thirds using the Obtura, with the result that the set sealer could not be adapted to the canal wall. This may explain why large sealer fragments appeared in many canals (Fig. 3) and the coronal two-thirds did not prevent FM in 35% of specimens. However, when viewed at a magnification of ×40, nearly 100% of the canal area was filled in the case of the VC group (Table 2), suggesting that the through-and-through voids present along many root fillings were too small to be seen at this magnification.

In this study, the gutta-percha was heated for 4 s using Touch 'n Heat at a power setting of 10. Under these conditions, the setting of RSA setting was a concern. The assumption that the increased FM associated with the VC technique and RSA was caused by the problem of sealer setting must be confirmed in further studies. In general, the setting time of sealers is usually measured at 37 °C (Higgenbotham 1967, Weiner & Schilder 1971, Caicedo & von Fraunhofer 1988, Allan *et al.* 2001) and not at the higher temperatures produced by heating devices.

On the other hand, the apical portion of gutta-percha was not warmed to the same temperature (Wu *et al.* 2002a), as heating was only carried out to a level 4 mm from the apex. When gutta-percha was compacted into the apical canal, the sealer in the apical one-third had not yet set and was adapted the canal wall. This may explain why the apical one-third of root fillings had minimal fluid movement in the study by Wu *et al.* (2002b).

In three SC cases, the root filling was displaced coronally during the root-end cavity preparation. This was probably caused by the RSA not adhering sufficiently to the dentine and being rubbery after setting. Clinically, this problem is unlikely to occur because immediate apical preparation is rarely carried out.

Conclusion

The coronal two-thirds of VC root fillings did not prevent fluid movement when the RSA sealer was used.

Acknowledgements

The authors wish to thank Drs J.G.J. Vercauteren and A.H. van Vliet for their laboratory work.

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